

REMARKS

The specification of the subject U.S. patent application, as filed, as constituted by the verified translation of PCT/DE2003/002467 has been cancelled in favor of the concurrently submitted Substitute Specification. A suitable Abstract of the Disclosure has been added. These changes and additions do not constitute any new matter.

Original claims 1-23, Article 19 claims 1-23 and further replacement claims 1-16 have all been cancelled. New claims 24-41 have been added. New claims 24-41 are essentially the same, in scope, as the claims now pending in the corresponding PCT application. They have been rewritten in a form more in accordance with U.S. practice.

Entry of this Preliminary Amendment into the file of the subject U.S. patent application, prior to the calculation of the filing fee, and prior to an examination of the application on the merits is respectfully requested.

Respectfully submitted,

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MARKED-UP COPY OF SPECIFICATION

LOHWEG: W1.1913 PCT-US

[Specification]

Methods [Method] for Evaluating the Signals of an Electronic Image Sensor During

Pattern Recognition of Image Contents of a Test Piece

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This U.S. patent application is the U.S. national phase, under 35 U.S.C. 371 of PCT/DE2003/002467, filed July 22, 2003; published as WO 2004/017252A1 on February 26, 2004, and claiming priority to DE 102 34 086.2 filed July 26, 2002, the disclosures of which are expressly incorporated herein by reference.

FIELD OF THE INVENTION

[0002] The present invention is directed [relates] to methods for signal evaluation of an electronic image sensor in the course of pattern recognition of the image contents of a test body [in accordance with the preambles of claims 1, 2 or 19]. The image sensor receives a light input signal and emits an electrical output signal which correlates with the light input signal.

BACKGROUND OF THE INVENTION

[0003] Known methods for analyzing the image contents of a test body are mainly based on metrics for determining similarities, such as distance measurements of segmented objects, or the calculation of global threshold distributions. These methods are based on translatorily invariable initial spectra. Situations often occur in reality, such as object

displacements underneath the recording system, or different backgrounds during recording, or aliasing effects, so that in many cases a direct comparison of these initial spectra cannot be performed.

[0004] It is known from the reference book of Thomas TILLI, "Mustererkennung mit Fuzzy-Logik: Analysieren, klassifizieren, erkennen und diagnostizieren" [Pattern Recognition by Means of Fuzzy Logic: Analyzing, Classifying, Determining and Diagnosing], Franzis-Verlag GmbH, München, publishers, 1993, pp. 183/184, 208 to 210, 235 to 257, to use fuzzy logic for image processing, wherein a spectral transformation can be one type of signal preparation.

[0005] The [In the] technical article "Mustererkennung mit Fuzzy- Logik" [Pattern Recognition by Means of Fuzzy Logic] by Peter ARNEMANN, Elektronik 22/1992, pages 88 to 92, describes [it is described] how to perform pattern recognition by the use [means] of fuzzy logic.

[0006] The article by D. Charalampidis, T. Kasparis, M. Georgiopoulos, J. Rolland "A Fuzzy ARTMAP-Based Classification Technique of Natural Textures", Fuzzy Information Processing Society, 1999, NAFIPS, 18th International Conference of the North American Fuzzy Information Processing Society, June 10 to 12 1999, pp. 507 to 511, describes the performance of pattern recognition with a training phase and the use of a window of 16 x 16 pixels for image recognition.

[0007] The publication "Volker Lohweg and Dietmar Müller: Ein generalisiertes Verfahren zur Berechnung von translationsinvarianten Zirkulartransformationen für die Anwendung in der Signal- und Bildverarbeitung" [A Generalized Method for Calculating Translation-invariant Circular Transformations for Employment in Signal and Image Processing], Mustererkennung [Pattern Recognition] 2000, 22nd DAGM Symposium, 09/13 to 15/2000, pages 213 to 220" describes the mathematical bases and the application of circular transformation in image processing.

[0008] USP 0,039,446/2002 discloses a method for comparing two patterns by the use of classification methods.

SUMMARY OF THE INVENTION

[0009] The object of the present invention is directed to [based on] providing methods for signal evaluation of an electronic image sensor in the course of pattern recognition of the image contents of a test body.

[0010] In accordance with the invention, this object is attained by generating a multiple pixel output signal with the image sensor. The output signal comprises an $n \times n$ pixel window within an image of the test body, whose contents are analyzed. The output signal is converted into at least one translationally invariant characteristic value by use of at least one calculation specification. In a fuzzification step, the characteristic value is weighted with a least one indistinct affiliation function. A higher order affiliation function is determined from the at least one affiliation function during an interference step. During

defuzzification, a sympathetic value is determined from the higher order affiliation function and is compared with a threshold value. A class affiliation is then decided from this comparison [the characteristics of claims 1, 2 or 19].

[0011] An advantage of the present invention lies, in particular, in that a sensor signal is analyzed in an image window of the size of $n \times n$ pixels. As a result of this, it is possible to consider the sensor signal of this image window to be local. The image analysis method in accordance with the present invention can be divided into the following substantial steps: characteristics formation, fuzzyfying, interference, defuzzyfying and decision regarding the class affiliation.

[0012] In the course of characteristics formation, the sensor signal is converted, by the use [means] of at least one calculation specification, into an invariant, and in particular into a translation- invariant, signal in the characteristic space. It is the aim of the characteristics formation to define those values by [means of] which typical signal properties of the image content are characterized. The typical signal properties of the image content are represented by so-called characteristics. In this case, the characteristics can be represented by values in the characteristic space, or by linguistic variables. A signal is formed [created] by transferring the sensor signal into the characteristic space, which consists of one characteristic value or of several characteristic values.

[0013] The affiliation of a characteristic value with a characteristic is described by at least one indistinct affiliation function. This is a soft or indistinct affiliation, wherein the

affiliation of the characteristic value with the characteristic exists as a function of the characteristic value in a standardized interval between 0 and 1. The concept of the affiliation function leads to a characteristic value no longer totally, or not at all, being capable of being affiliated with a characteristic, but which instead can take on a fuzzy affiliation, which is located between the Boolean logical functions 1 and 0. The above- [just] described step is called fuzzyfication. Thus, in the course of fuzzyfication, a conversion of a definite characteristic value into one or into several indistinct affiliations substantially takes [substantially] place.

[0014] In connection with the interference step, a higher order affiliation function is generated by use [means] of a calculation specification consisting of at least one rule, wherein all of the affiliation functions are linked to each other. As a result, a higher order affiliation function is therefore obtained for each image window.

[0015] In connection with the defuzzyfication step, a number value, also called a sympathetic value, is determined from the higher order affiliation function formed during interference. In the course of the decision regarding class affiliation, a comparison of the sympathetic value with a previously fixed threshold value takes place, by [means of] which comparison the affiliation of the window with a defined class is decided.

[0016] What type the characteristic values in the characteristic space are is of lesser importance for the principle of the present invention. Thus, for example, in connection with time signals, there is the possibility to set the mean value or the variance as

characteristic values. If it is required of the evaluation process that it can process the image contents free of errors, regardless of the respectively prevailing signal intensity, and if furthermore small, but permissible fluctuations in the image signal do not lead to interference, it is useful if the conversion of the sensor signal from the two-dimensional local space is performed by the use [means] of a two-dimensional spectral transformation, such as, for example, a two-dimensional Fourier, or a two-dimensional Walsh, or a two-dimensional Hadamard, or a two-dimensional circular transformation. Invariant characteristic values are obtained by the use [means] of the two-dimensional spectral transformation. A further preferred embodiment of the present invention consists in using the amount of the spectral coefficient obtained by the spectral transformation as the characteristic value.

[0017] In a preferred [exemplary] embodiment of the present invention, the affiliation functions are unimodal potential functions, and the higher order affiliation function is a multimodal potential function.

[0018] In accordance with a further preferred [exemplary] embodiment of the present invention, at least one affiliation function is parametrized. If the affiliation function has positive and negative slopes, it is advantageous if it is possible to determine the positive and negative slopes separately. An improved matching of the parameters to the data sets to be examined is assured by this.

[0019] In accordance with a particularly preferred [exemplary] embodiment of the present invention, the method for evaluating the images of the electronic image sensor can be divided into a learning phase and a working phase. If the affiliation functions are parametrized, it is possible, in the learning phase, to determine the parameters of the affiliation functions from measured data sets. In the learning phase, the parameters of the affiliation functions are adapted to so-called reference images, i.e. during the learning phase an affiliation of the characteristic values resulting from the reference images with the respective characteristics is derived by the use [means] of the affiliation functions and their parameters. In the subsequent work phase, the characteristic values resulting from the now measured data sets are weighted with the affiliation functions whose parameters had been determined in the learning phase, from which step an affiliation of the characteristic values of the now measured data sets with the corresponding characteristics is produced. By dividing the method into a learning phase and a work phase, the parameters of the affiliation functions are determined by the use [means] of measured reference data sets. In [, and in] the subsequent work phase, the measured data sets, which are to be tested, are weighted with the affiliation functions fixed during the learning phase, and are then evaluated.

[0020] In accordance with a further preferred [exemplary] embodiment of the present invention, at least one rule by [means of] which the affiliation functions are linked with each other, is a conjunctive rule within the meaning of an IF ...THEN linkage.

[0021] A further preferred [exemplary] embodiment of the present invention subdivides the generation of the higher order indistinct affiliation functions into the processing of the partial steps: premise evaluation, activation and aggregation. In this case, in the premise evaluation partial step, an affiliation value is determined for each IF portion of a rule, and during the activation step, an affiliation function is fixed for each IF ... THEN rule. Thereafter, during the aggregation step, the higher order affiliation function is generated by superimposing all of the affiliation functions created during the activation step.

[0022] In accordance with a further preferred [exemplary] embodiment of the present invention, the sympathetic value determination is performed, in particular, in accordance with a main emphasis and/or a maximum method.

BRIEF DESCRIPTION OF THE DRAWINGS

[0023] Preferred [Exemplary] embodiments of the present invention are represented in the drawings and will be described in greater detail in what follows.

[0024] Shown are in:

Fig. 1, a flow diagram of the signal evaluation method in accordance with the present invention, in

Fig. 2, a sympathetic curve, in

Fig. 3a, a difference function of the power of $D = 8$, in

Fig. 3b, a difference function of the power of $D = 4$, and in

Fig. 3c, a difference function of the power of $D = 2$

DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0025] A flow diagram of the signal evaluation method to be described in what follows, in accordance with the present invention, is shown in Fig. 1. In [With] the method for signal evaluation of image contents of a test body, a grid of $N \times N$ windows 01 is placed over the entire image to be analyzed. Each window 01 here consists of $n \times n$ pixels 02. In the course of the image analysis, the signal from each window 01 is analyzed separately. As a result, the image content 03 of each window 01 can be considered to be local.

[0026] The two-dimensional image of the local space is transformed into a two-dimensional image in the frequency space by one or by several spectral transformations. The spectrum obtained is called a frequency spectrum. Since this is a discrete spectrum in the present preferred [exemplary] embodiment, the frequency spectrum is also discrete. The frequency spectrum is constituted by the spectral coefficients 06, which are [-] also called spectral values 06 [-].

[CORRECTED PAGE (RULE 91)]

[0027] In the subsequent [next] method step, the amount formation 07 of the spectral values 06 takes place. The amounts of the spectral values 06 are [is] called spectral amplitude values 08. In the present preferred [exemplary] embodiment, the

spectral amplitude values 08 constitute the characteristic values, i.e. they are identical to the characteristic values.

[0028] A circular transformation is preferably used for the transformation. With the circular transformation, the invariance properties can be adjusted via the transformation coefficients. It is possible to set a translation invariance, as well as a reflection invariance, or an invariance with [in] respect to different other permutation groups. In this way, it is possible to utilize the above mentioned transformation, for example, in the reflection-variant variation for inspecting characters. Consider [(consider)] the differentiation between the numbers "9" and "6"[]]. In the same way, the reflection-invariant variation can be used for inspecting workpieces, since here it is not necessary, in particular, to make a differentiation between a reflected part and the original. It should be mentioned that the amount spectrum of the Fourier transformation is reflection-invariant.

[0029] These transformations work with real coefficient values. It is therefore not necessary to utilize a complex calculation, as with the Fourier transformation.

[0030] The circular transformation is extremely tolerant, even in the sub-pixel range, in connection with any arbitrary displacements. Comparisons have shown that this circular transformation is superior to other known transformations in regard to displacements.

[CORRECTED PAGE (RULE 91)]

[0031] The number of work coefficients (characteristics, features) is small, because the spectral coefficients are again combined in groups.

[0032] The tolerance to displacements is created by the combination. Even if a signal runs partially out of a measurement field, the characteristics remain relatively stable. Tests have shown that stability is maintained, even if the image contents lie outside of the measurement field by up to approximately 30%.

[0033] The characteristic selection 09 follows as a further method step. The [; the] aim of the characteristic selection 09 is to select the characteristics 11, which are characteristic for the image content 03 of the image to be analyzed. Characteristic spectral amplitude values 08, which define the characteristic 11 by their position in the frequency space and by their amplitude, are possible as characteristics 11. Linguistic [, but also linguistic] variables, such as "gray", "black" or "white", are also possible as characteristics 11.

[0034] In the next [following] method step, the fuzzyfication step 12, the affiliation of each spectral amplitude value 08 with a characteristic[s] 11 is fixed by the use [means] of a soft or an indistinct affiliation function 13. In other words, [, i. e.] weighting is performed.

[0035] If it is intended, during a learning phase, to match the affiliation functions 13 to so-called reference data sets, it is useful if the affiliation functions 13 are parametrized monomodal, i.e. are one-dimensional potential functions, wherein the

parameters of the positive and negative slopes can be matched separately to the data sets to be examined. In the work phase₂ which follows the learning phase, the data sets of the image content₁ from which the characteristic values 08 of the test images result₁ are weighted with the respective affiliation functions 13 whose parameters had been determined in the previous learning phase. This means that₁ for each characteristic 11, a sort of TARGET-ACTUAL comparison between the reference data set, expressed in the parameters of the affiliation function 13, and the data set of the test image takes place. A soft or indistinct affiliation between the respective characteristic value 08 and the characteristic 11 is made by use [means] of the affiliation functions 13.

[0036] In the next method step, the interference step 14, a conjunctive linkage 15₁ [-] also called aggregation 15₁ [-] of all affiliation functions 13 of the characteristics 11 takes place. A [, so that a] higher order affiliation function 16 is thus created or formed.

[0037] The next method step, the defuzzification step 17, determines a concrete affiliation or sympathetic value 18 from the higher order affiliation function 16. During the classification 19, this sympathetic value 18 is compared with a previously set threshold value 21, so that a classification statement can be made. The threshold value 21 is set either manually or automatically. Setting of the threshold value 21 takes also place during the learning phase.

[0038] During the classification, a numerical value is not assigned directly to a defined class by the use [means] of a true or false statement. A [, a] unimodal function is set instead, which function describes an affiliation with a true or false statement.

[0039] In the course of this, the class affiliation is trained, i.e. the decision curves are taught by the use [means] of measured values determined during the process. The functions by [means of] which a degree of affiliation is determined, are called affiliation functions $ZGF = \mu(m_x)$. The calculated value of the affiliation function ZGF is called a sympathetic value μ . Several affiliation functions ZGF are often used, which are further combined in the subsequent steps in order to achieve an unequivocal statement.

[0040] However, this is specifically not a neuronal network being used. It is known that neuronal networks can be trained.

[0041] The fuzzy plate classification is based on a concept which simultaneously provides a distance measurement and a characteristic linkage. The "fuzzy" fact here is that the characteristics are "rounded off", not logically, but indistinctly. For one, this leads to all characteristics being summarily considered. This means that small deviations from a characteristic are still tolerated. If, secondly, the deviation from a characteristic becomes too large, this immediately has [immediately] a large effect on the distance measurement. Accordingly, the output of the classifier does not provide a "good/bad" decision, but a continuous output value between [0 ... 1]. Thereafter a threshold value is used, which makes a "good/bad" decision possible.

[0042] The output value for the distance measurement (sympathetic value) is

$\mu = 2^{-z}$, wherein

$$z = \frac{1}{M} \sum_{x=0}^{M-1} \left(\frac{|m_x - x_0(m_x)|}{C_x} \right)^D, 0 \leq z \leq 10, z > 10 \Rightarrow \mu(z) \equiv 0,$$

[0043] Here, the coefficients have the following meanings: x = counting index, z = averaged distance measurement, M = number of characteristics, x_0 = mean value of C_{diff} , C_x = expansion value, D = power, μ = sympathetic value, C_{diff} = difference measurement of the expansion value.

[0044] The expansion value C is taught with the aid of measured values which had been generated by the use [means] of the circular transformation.

[0045] The μ -value describes how close the similarity of a pattern is in relation to a reference pattern described by the characteristics. This means that the z -value takes over the actual control of the μ -value. If the z -value is very small, the μ -value is close to 1. The patterns are very similar, or are [(sympathetic)]. However, if the z -value is large, the μ -value will become small. This indicates that [,] the patterns are not similar. The course of the curve, [-] as implemented, [-] is represented in Fig. 2.

[0046] Initially, in the learning phase, the values C_{diff_x} are determined, namely for each characteristic m_x one value:

$$C_{\text{diff}_x} = \max(m_x) - \min(m_x)$$

wherein C_{diff} is the difference measurement of the expansion value, and m are the characteristics.

[0047] During the inspection, the learned C_{diff} values are used. The values can still be assigned an additional tolerance a . Settlement takes place during the running time:

$$C_x = (1 + 2 p_{ce}) \frac{\max(m_x) - \min(m_x)}{2}, a = (1 + 2 p_{ce})$$

wherein C is the expansion value and P_{ce} is the percental tolerance of C_{diff} .

[0057] The value range of " a " lies between [1 ... 3]. The value P_{ce} indicates the percental tolerance with which C_{diff} is respectively charged. A 50% expansion of the range of C_{diff} is intended to be achieved; in that case " a " = $1+2*0.5 = 2$.

[0058] The x_0 value indicates the mean value of C_{diff} ; it is calculated for each characteristic during the running time.

[0059] The difference between the characteristic value and the mean characteristic value, which is determined from the value C_x , is calculated. This difference is standardized with the width of the expansion value C_x . The result is that, with a slight deviation, the corresponding characteristic contributes little to the z-value. However [; however], with a large deviation, a large deviation value will result as a function of the difference measure of the expansion value C_{diff} . The standardized difference is called d_x .

[0060] The power D (2, 4, 8) sets the sensitivity at the flanks of the standardized difference function d_x . If the value D is set to "infinity", [-] which is not technically possible, [-] an infinite flank steepness is also obtained, and therefore a hard good/bad

decision is made. Therefore, the values are customarily set to between 2 ... 20. The curves for the values 2, 4 and 8 are represented in Figs. 3c, 3b and 3a.

[0061] The exponentiated functions d_x are added up. However [, however], only the number M of the characteristics m which have been switched on is used. Following the adding-up, the calculated value is divided by the number M. The mean value of all exponentiated differences d_x is thus determined.

[CORRECTED PAGE (RULE 91)]

[0062] The effect is the following: because of the exponentiation, small deviations will not be important, but the importance of large ones will be increased. A deviation of all characteristic differences is calculated by averaging. This has the result that, even with the deviation of several characteristics, the μ -value is not drastically lowered. This value will become very small only with larger deviations.

[0063] A threshold value evaluation follows thereafter.

$$\mu_{\text{klass}} = \begin{cases} \text{Good, if } \mu(z) \geq \mu_s \\ \text{Error, if } \mu(z) < \mu_s \end{cases}$$

[0064] This process is performed for all windows.

[0065] An evaluation of dynamic processes, [-] such a printing processes, [-] requires non-linear distance measurements or [(sympathetic values)].

[0066] While preferred embodiments of methods for evaluating the signals of an electronic image sensor during pattern recognition of image contents of a test piece, in accordance with the present invention, have been set forth fully and completely hereinabove, it will be apparent to one of skill in the art that various changes in, for example the specific image to be evaluated, the specific type of electronic image sensor used to receive the light input signal, and the like could be made without departing from the true spirit and scope of the present invention which is accordingly to be limited only by the following claims.

[0067] WHAT IS CLAIMED IS:

[List of Reference Symbols]

- 01 Window, $N \times N$ windows
- 02 $n \times n$ pixels
- 03 Image contents
- 04 2-dimensional spectral transformation,
calculation specification
- 05 -
- 06 Spectral coefficient, spectral value
- 07 2-dimensional amount formation, calculation
specification
- 08 Spectral amplitude value=characteristic value
- 09 Characteristics selection
- 10 -
- 11 Characteristic
- 12 Fuzzyfication
- 13 Affiliation function
- 14 Interference, calculation specification
- 15 -
- 16 Higher order affiliation function, linkage,
aggregation
- 17 Defuzzyfication
- 18 Affiliation value, sympathetic value
- 19 Classification, class affiliation
- 20 -
- 21 Threshold value

- C Expansion value
- C_{diff} Difference measure of the expansion value
- D Power
- M Number of characteristics
- ZGF Affiliation function]

[a	Tolerance
d_x	Nominated difference
m	Characteristic
p_{ce}	Percental tolerance of C_{diff}
x	Counting index
z	Averaged distance measurement
μ	Sympathetic value, distance measurement]

Addendum**Attachment 1**

- A) Five (5) sheets of Formal Drawings
- B) WO 2004/017252 A1 published February 26, 2004
- C) Request for Removing Defects mailed September 16, 2003, with translation
- D) Response by KBA on September 29, 2003, with translation
- E) International Search Report of January 15, 2004, with translation
- F) Chapter II Demand, dated January 29, 2004
- G) Letter from KBA with Article 19 claims dated January 28, 2004, with translation
- H) Request for Thorough Examination dated January 28, 2004, with translation
- I) Written Opinion dated June 16, 2004, with translation
- J) Letter from KBA dated July 5, 2004, with translation
- K) IPER dated October 15, 2004, with translation